HTML ABSTRACT + LINKS

COMPASS: a 2.6m telescope for CMBR polarization studies

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Abstract. COMPASS (COsmic Microwave Polarization at Small Scale) is an experiment devoted to measuring the polarization of the CMBR. Its design and characteristics are presented.

INTRODUCTION

The 2.7K Cosmic Microwave Background Radiation (CMB) is one of the few tools we have for understanding the origin of the universe. This radiation provides a "snapshot'' of the epoch at which radiation and matter decoupled, approximately 300,000 years after the Big Bang, and can tightly constrain theories of cosmological structure formation. There is no other known direct probe of the universe at such early times.

The three defining characteristics of this radiation are: its spectrum, spatial anisotropy, and polarization. The beginnings of structure formation through gravitational collapse should appear in the spatial distribution of the CMB; the COBE/*DMR* detected spatial anisotropy of the CMB on $10°$ scales of $\Delta T/T \approx 1.1 \times 10^{-5}$ (Bennett *et al.* 1996) and ground-based and balloon-borne experiments have also detected anisotropy at smaller scales (Netterfield et al., 2001, Halverson et al, 2001, Lee et al, 2001). Despite these new results, important questions remain. Does the observed CMB emanate directly from the decoupling era, or has it instead scattered from free electrons in an intervening reionization of the universe? What is the mechanism that produces the large-scale structure in the universe? What is the expansion rate of the universe? What causes the universal expansion and is it accelerating? What is the nature of the dark matter?

It is now clear, however, that the temperature anisotropy measurements alone will not answer all of these questions. Presently, the standard cosmological models require specification of more than 10 parameters. The anisotropy measurements must be combined with additional data sets to break the degeneracies in the models. Therefore we have undertaken a program to measure the third defining characteristic of the CMB, its *polarization*. The temperature anisotropy and the polarization of the CMB both depend on the power spectrum of fluctuations in the early universe as well as the ionization history of the universe, but they do so in different ways. The angular power spectrum of temperature anisotropy and polarization are both determined by factors such as: the source of the CMB anisotropy, the density parameter Ω, the baryon content of the universe Ω_B, and the Hubble constant, H_0. However, the CMB polarization is uniquely sensitive to photon rescattering after the decoupling era (*i.e.* it depends on the duration of recombination and the epoch of reionization), to the *velocity* of matter at the last scattering surface, and to the presence of gravitational waves in the early universe.

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The predicted polarization amplitude is extremely small, less than one-part in 10^6 of the CMB intensity, or $\Delta T_{Pol}/T \leq 1\times10^{-6}$. This signal is more than an order of magnitude below current upper limits; detecting it poses an extremely challenging task, requiring high-sensitivity detectors, careful attention to systematic effects, and knowledge that we do not yet possess about polarized foreground emission. Using an existing polarimeter from Madison, WI, we plan to detect this signal by integrating for a long period on a limited portion of the sky. However, these measurements will not be able to discriminate fully against foreground sources, and lack the sensitivity required to measure the angular power spectrum which encodes so much primordial information.

The most formidable unknown in these measurements is emission from foreground sources. COMPASS will complement other measurements of CMB polarization, including our own POLAR, by increasing the sensitivity and extending the frequency coverage beyond current observations. The latter is essential to discrimination against foreground emission from galactic and extragalactic sources.

COMPASS operates in the Ka-band (26-36 GHz) and has a beam size of 20' FWHM. In its first season of operation it searched for CMBR polarization in the North Celestial Pole region from Madison (WI-USA) from late winter through spring 2001. We give here few details of the instrument design and performance.

THE INSTRUMENT

COMPASS is a 2.6 meter diameter on-axis reflector with many novel features. The on-axis design was chosen to minimize the polarization offsets that can be induced by the primary mirror. The secondary mirror is held in position by a cone of transparent foam. We opted for this solution to minimise the scattering of radiation from any metal struts. The emissivity of the foam has been measured to be 0.5% ± 0.25%. The polarimeter at the focal plane is the POLAR receiver (Keating et al., 2001a and 2001b). The instrument uses two cooled HEMT amplifiers (at about 20K) in a correlation polarimeter configuration. The polarimeter achieved high sensitivity and stability over integration times of more than 100 hours. The RF band (Ka) is divided into 3 sub-bands spanning the 26-36 GHz frequency interval. We record three correlator outputs J1 (32-36 GHz), J2 (29-32 GHz) and J3 (26-29 GHz) corresponding to the three sub-bands, plus two total power outputs TP1 and TP2 integrating the full band of each HEMT amplifier. The receiver includes a corrugated scalar feedhorn (6 degrees FWHM) with a teflon lens to couple to the Cassegrain sub-reflector. The illumination on the sub-reflector and then on the primary mirror is respectively –25 and -16 dB. The resulting beam in the sky is about 20'.

Extensive noise measurements and tests have been performed before, during and after the 2001 winter/spring campaign. In Table 1 we report the measured sensitivity of COMPASS fully integrated and observing a blank sky region.

TABLE 1. Noise performances

	Noise mK √s (thermodynamic)	RF band GHz
J1	1.1	32-36
J2	1.0	29-32
J3	0.8	26-29
TP1	≈5	26-36
TP2	≈5	26-36

The beam pattern has been measured by observing a remote GUNN oscillator positioned on a high tower in the far field. Repeated scans of the Gunn oscillator provided a very accurate measurement of the main beam. The beam has been checked also by observing known sky objects (Venus, Tau A and Cas A).

Calibration was performed by executing different scans of the polarized source Tau-A.This source is not resolved in our beam and is known to be polarized at a level of 6.6% (Flett & Henderson, 1979). The over-all preliminary calibration accuracy is about 20%.

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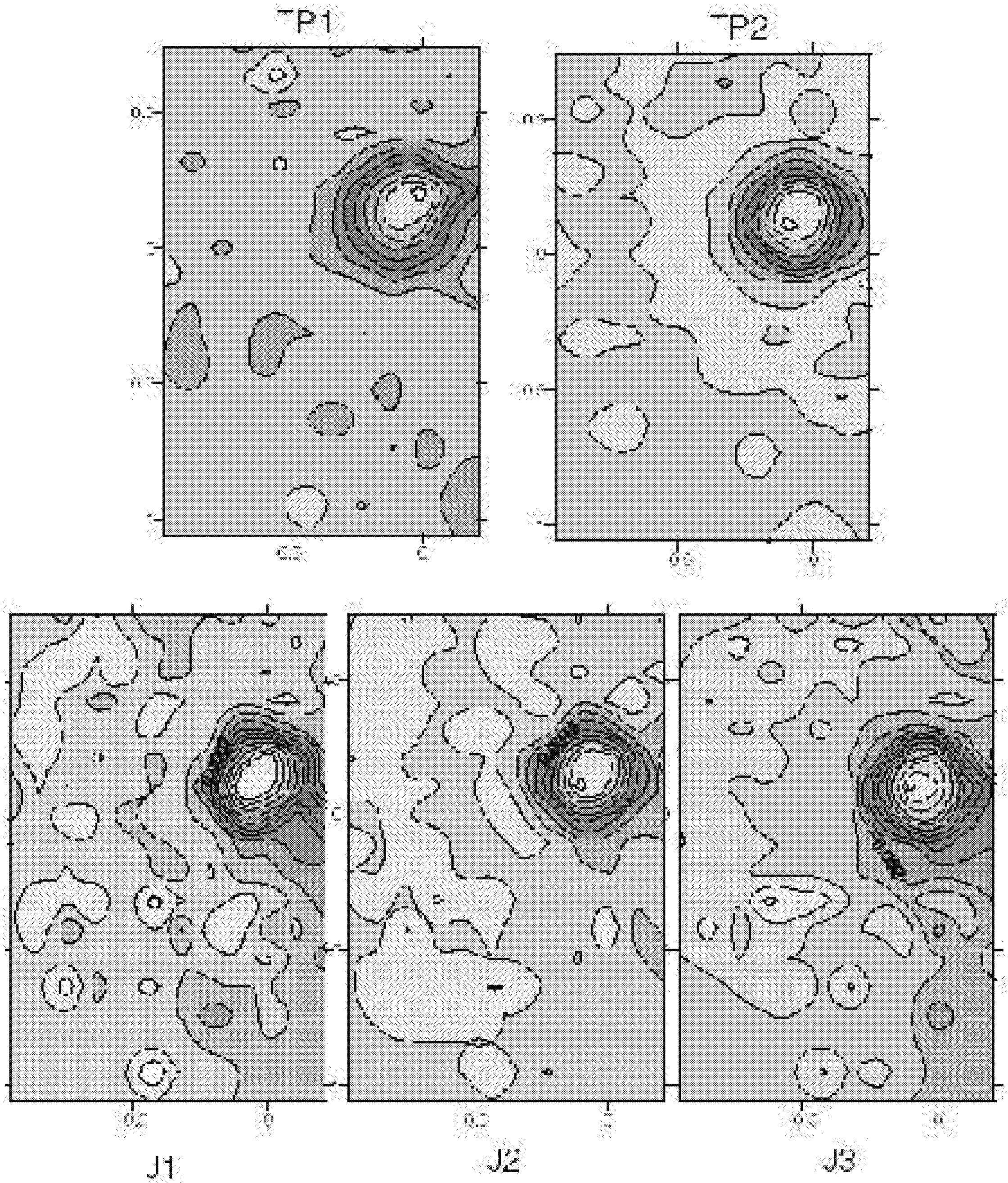

FIGURE 1. Maps of the polarized source Tau-A. TP1 and TP2 are the two total power channels. J1, J2 and J3 are the three correlator sub-bands.

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The observing strategy was designed to achieve enough sensitivity per pixel in the sky and sky coverage given the noise performances and the amount of good observing time available. In Madison, WI, where the telescope is installed, we hope to have about 15% observing efficiency or roughly two full months per year. In our first observing campaign, from March to May 2001 we collected about 50 hours of usable data in Q mode. We scanned a cap (1.8 degrees diameter) around the North Celestail Pole (NCP) for a total of 30 pixels. This first campaign will produce a map with an expected noise of about 13 μK per pixel.

We are in the process of comparing our data set with other observations of the same sky region. In particular we will cross-correlate with the QMASK data looking for potential foregrounds. A companion survey with the Effelsberg 100 meter telescope at 32 GHz is under way looking for point sources contamination.

We plan to use COMPASS to observe the same region of the sky again starting in fall 2001. The polarimeter observes only one Stokes parameter at a time, but by rotating the polarimeter with respect to the telescope in steps of 45 degrees, we can measure U and Q on the sky. We are also developing a 90 GHz polarimeter that we hope to mount on the COMPASS telescope in early 2002 to help sort out any foreground signals that might be present in the 30 GHz data. In this configuration we expect a beam size of 7' and plan to map the same NCP region again in both Stokes parameters.

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